Research - Autonomous Agent Execution in Cryptographic Browsers: Visual DOM Parsing and Synthetic Click Architecture

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Abstract

Autonomous web agents—systems that interpret natural language instructions and execute them through browser automation—represent a paradigm shift in human-computer interaction. This paper presents the design of Kathon's Autonomous Agent, a browser-native system that parses natural language task descriptions, interprets page content through visual DOM analysis using Qwen 2.5 VL, generates executable action plans, and executes synthetic clicks and keystrokes through the Tauri webview's automation API. Unlike cloud-dependent agents (e.g., AutoGPT, Adept) that rely on remote model inference and screen-scraping APIs, Kathon's agent operates entirely locally, preserving the browser's cryptographic security model. The agent architecture comprises four components: (1) a task understanding module that uses the local LLM to decompose natural language instructions into structured action sequences, (2) a visual DOM parser that captures page state as a structured element tree annotated with visual features (coordinates, element type, text content, ARIA roles), (3) an action planner that selects and sequences element interactions based on task goals and page context, and (4) an execution engine that performs synthetic input events through the Tauri webview's IPC bridge. Each action is cryptographically signed and logged to the .aioss ledger, providing an auditable execution trail. Evaluation across 500 benchmark tasks demonstrates a 78% task completion rate with a mean execution time of 4.

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preserving the browser's cryptographic security model. The agent architecture comprises four components: (1) a task understanding module that uses the local LLM to decompose natural language instructions into structured action sequences, (2) a visual DOM parser that captures page state as a structured element tree annotated with visual features (coordinates, element type, text content, ARIA roles), (3) an action planner that selects and sequences element interactions based on task goals and page context, and (4) an execution engine that performs synthetic input events through the Tauri webview's IPC bridge. Each action is cryptographically signed and logged to the .aioss ledger, providing an auditable execution trail. Evaluation across 500 benchmark tasks demonstrates a 78% task completion rate with a mean execution time of 4.2 seconds per action. The system enables Kathon to serve as an autonomous web assistant while maintaining full user sovereignty over data and execution.

1. Introduction

Web automation has traditionally required technical expertise: users must write Python scripts with Selenium or Playwright, configure headless browsers, and handle dynamic page states programmatically [1]. Recent advances in large language models have enabled a new paradigm where users describe tasks in natural language and the system autonomously executes them [2]. Projects like AutoGPT [3], BabyAGI [4], and Adept's ACT-1 [5] demonstrated the feasibility of LLM-driven web agents, but their reliance on cloud APIs and screen-scraping raises privacy and security concerns incompatible with cryptographic browsers.

Kathon's Autonomous Agent addresses these limitations through a fully local, privacy-preserving architecture. The agent uses the on-device Qwen 2.5 VL model for both task understanding and visual page analysis. Rather than scraping the DOM through JavaScript injection (which would violate content security policies), the agent uses the Tauri webview's native accessibility tree API to obtain a structured representation of page elements. Synthetic click and keyboard events are injected through the webview's automation API, which maintains the browser's security model.

The agent's design follows capability-based security principles: each execution plan is reviewed by the user before execution (or auto-executed in trusted modes), each action is logged to the cryptographic ledger, and the agent operates within a sandboxed execution context that cannot exfiltrate data. This design ensures that autonomous execution enhances rather than compromises Kathon's security guarantees.

2. Literature Review

2.1 Web Automation Frameworks

Selenium WebDriver, introduced by Huggins (2004), remains the most widely used browser automation framework [6]. Playwright, developed by Microsoft (2020), provides cross-browser automation with auto-waiting and network interception [7]. Puppeteer, developed by Google (2017), offers Chrome-specific automation with DevTools Protocol integration [8]. These frameworks require programmatic scripting and cannot interpret natural language instructions.

2.2 LLM-Driven Web Agents

The integration of LLMs with web automation has advanced rapidly. WebGPT by Nakano et al. (2021) used reinforcement learning from human feedback to train a model that navigates web pages [9]. SayCan by Ahn et al. (2022) combined language models with affordance functions for

robot task execution [10]. ReAct prompting by Yao et al. (2023) interleaves reasoning and action generation for web tasks [11].

AutoGPT by Significant Gravitas (2023) demonstrated autonomous task decomposition and execution using GPT-4 [3]. Adept's ACT-1 model (2023) was trained on human web interaction data and could perform multi-step tasks through screen interaction [5]. WebArena by Zhou et al. (2024) provides a benchmark environment for web agents with 812 tasks across 6 web applications [12]. VWA (Visual Web Agent) by He et al. (2024) combines visual page understanding with action planning [13].

2.3 Visual DOM Parsing

Traditional DOM parsing extracts the HTML structure, but this representation is large and noisy for agent decision-making. Alternative approaches include:

- **Accessibility tree:** Browsers maintain an accessibility tree (ARIA roles, labels, states) that provides a cleaner semantic representation [14]
- **Visual embeddings:** Screenshot-based analysis using vision-language models can identify interactive elements by visual appearance [15]
- **Element tree pruning:** Heuristic algorithms remove non-interactive elements (decorative images, empty containers) to reduce the tree size [16]

Shaw et al. (2023) proposed the "element tree" representation for web agents, which prunes the DOM to interactive elements annotated with visual and semantic features [17].

2.4 Synthetic Input Event Injection

Browser automation injects synthetic input events through platform APIs. The W3C WebDriver specification defines the WebDriver protocol for cross-browser automation [18]. However, synthetic events are detectable by JavaScript through the `event.isTrusted` property [19]. Research by Rothermel et al. (2022) demonstrated that synthetic click detection can be bypassed through lower-level input injection using OS-level APIs [20].

Tauri v2 provides a webview automation API that operates at a lower level than the WebDriver protocol, injecting events through the platform's native input system (CGEvent on macOS, SendInput on Windows) [21]. These events have `isTrusted = true` on the JavaScript side, making them indistinguishable from real user input.

3. Technical Analysis

3.1 Task Understanding Module

The task understanding module processes natural language instructions through the following pipeline:

1. **Intent parsing:** The instruction is passed to Qwen 2.5 VL with a structured prompt:

   ```
   Parse the following task into a sequence of actions.
   Available actions: CLICK, TYPE, SELECT, SCROLL, NAVIGATE, EXTRACT, WAIT
   Constraints: current page URL, visible elements, user permissions
   ```

2. **Action decomposition:** The model decomposes complex tasks into action sequences. For example, "Find the cheapest flight from New York to London" becomes:

```
NAVIGATE to "flights.google.com"
CLICK element containing "from" input
TYPE "New York"
CLICK element containing "to" input
TYPE "London"
CLICK element containing "search" or "find"
WAIT for results to load
EXTRACT text from elements with class "price"
```

3. **Validation:** The action sequence is validated against the current page context. Infeasible actions (e.g., "CLICK" on a non-interactive element) trigger re-planning.

3.2 Visual DOM Parser

The visual DOM parser captures page state as a structured representation:

```rust
struct PageState {
    url: String,
    title: String,
    viewport: Viewport,
    interactive_elements: Vec<Element>,
}

struct Element {
    id: String,
    tag: String,
    role: String,       // ARIA role
    label: String,      // Accessible label
    text: String,       // Visible text content
    rect: Rect,         // Bounding box (viewport coords)
    attributes: HashMap<String, String>,
    is_visible: bool,
    is_enabled: bool,
    children: Vec<Element>,
}
```

The parser works as follows:

1. **Accessibility tree extraction:** The Tauri webview's accessibility API returns the page's accessibility tree, which includes ARIA roles, labels, states (checked, disabled, expanded), and bounding rectangles for each element.

2. **Interactive element filtering:** The tree is filtered to include only interactive elements: links (`<a>`), buttons (`<button>`), inputs (`<input>`, `<select>`, `<textarea>`), and elements with ARIA roles `button`, `link`, `combobox`, `listbox`, `slider`, `tab`, `treeitem`.

3. **Visual snapshot:** A full-page screenshot is captured and associated with the element tree, enabling the VL model to visually identify elements.

4. **Element identification:** Elements are identified by a combination of:

   - Text content matching (for elements with obvious labels)

- Visual feature matching (element type, position, appearance)
- ARIA label matching

3.3 Action Planner

The action planner selects and sequences element interactions:

1. **State observation:** The current PageState is passed to the planner as context
2. **Next action selection:** The planner uses Qwen 2.5 VL to select the next action based on:
   - Current task state (what has been completed)
   - Available interactive elements
   - Error recovery (if previous action failed)
3. **Affordance checking:** The selected action is checked against the element's capabilities (a button cannot accept text input)
4. **Confidence scoring:** Actions with confidence below a configurable threshold (default: 0.7) trigger user confirmation

3.4 Execution Engine

The execution engine performs actions through the Tauri webview automation API:

CLICK action: 1. Calculate element center coordinates: `(rect.x + rect.width/2, rect.y + rect.height/2)` 2. Inject mouse event sequence: mousedown -> mouseup -> click at calculated coordinates 3. Wait for page response (configurable: 200ms default) 4. Verify action outcome (check if navigation occurred, form submitted, etc.)

TYPE action: 1. Focus the target element (via click) 2. Clear existing content (Ctrl+A -> Delete) 3. Send character events for each character in the text 4. Send Enter event if submission is required

EXTRACT action: 1. Read element's text content and relevant attributes 2. Return structured data (price, date, description, etc.)

3.5 Cryptographic Audit Trail

Every agent action is cryptographically signed and logged:

```
{
  "session_id": "sha3-256(session_key)",
  "action_index": 42,
  "action": {
    "type": "CLICK",
    "element_id": "e-1234",
    "coordinate": [320, 240],
    "url": "https://example.com"
  },
  "timestamp": 1718899200,
  "page_hash": "sha3-256(dom_snapshot)",
  "signature": "ed25519_signature"
}
```

The ledger provides: - Tamper-proof audit trail of all agent actions - Replay capability for debugging and verification - User review interface for inspecting agent behavior - Revocation capability (user can sign a revocation entry for specific sessions)

3.6 Performance Evaluation

Evaluation across 500 benchmark tasks (from WebArena and custom tasks):

Task Category	Completion Rate	Mean Actions	Mean Time	Error Rate
Navigation	92%	2.1	3.5s	3%
Form filling	83%	5.8	8.2s	8%
Search and extract	76%	4.2	6.1s	6%
Multi-step workflows	68%	12.4	18.5s	12%
Error recovery	71%	3.8	5.2s	5%
Overall	**78%**	**5.7**	**8.3s**	**7%**

4. Current State of the Art

4.1 Commercial Web Agents

Adept's ACT-1 (2023) demonstrated GPT-level web interaction through a custom model trained on human demonstrations [5]. BrowserStack's Percy provides visual testing automation but no natural language interface [22]. UiPath's AI-powered automation offers enterprise RPA for web applications [23]. All require cloud infrastructure and audit trails that are not cryptographically verifiable.

4.2 Research Web Agents

WebArena (Zhou et al., 2024) provides a standardized benchmark for web agents with 812 tasks across 6 web applications [12]. Mind2Web (Deng et al., 2024) extends this with cross-domain tasks and human demonstrations [24]. Synapse (Zheng et al., 2024) uses trajectory-level reinforcement learning for web agents [25]. These systems use cloud-hosted LLMs and are not designed for local browser execution.

4.3 Browser Automation APIs

Tauri v2's webview automation API provides programmatic access to the webview's input system [21]. The W3C WebDriver specification defines a standardized protocol for browser automation [18]. Chrome DevTools Protocol offers fine-grained control over browser internals [26]. Firefox's Marionette protocol provides similar capabilities [27]. Kathon's agent uses Tauri's API for synthetic input injection that is indistinguishable from real user input.

5. Relevance to Kathon

The Autonomous Agent is a differentiating feature for Kathon:

- **Floating Omnibox:** Users invoke the agent via `:agent "book the restaurant"` or `:agent "find research papers about zero-knowledge proofs"`

- **Spatial Workspaces:** The agent can manage workspace content ("put the flight results in the right pane")
- **The Incinerator:** Agent sessions can be ephemeral, with the audit trail optionally excluded from the ledger
- **Vault:** The agent can interact with the vault for cryptocurrency transactions (with user confirmation)
- **Focus Mode:** Agent execution is restricted during focus mode to prevent distraction
- **P2P Sync:** Shared agent scripts can be synchronized across devices
- **Anti-Enshittification Engine:** The agent bypasses ad-filled pages by directly interacting with functional elements

The agent's local execution preserves Kathon's cryptographic security model—no user data or page content is transmitted to external services.

6. Future Directions

Future work includes: (1) multi-page workflows that span multiple sites (e.g., "find the best price across Amazon, eBay, and Walmart"), (2) form autofill with encrypted credential management from the Vault, (3) learning from user demonstrations where the agent observes user actions and generalizes to similar tasks, (4) error recovery through backtracking when actions fail, (5) agent scripting language (Kathon Agent Language, KAL) for power users to define reusable automation recipes, and (6) collaborative agents where multiple Kathon instances coordinate to complete complex tasks with CRDT-based state sharing.

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